

MORPHOLOGICAL CHANGES IN MUSCLES AND NERVES OF
THE EXTREMITIES UNDER CONDITIONS OF "OVERTRAINING"

P. Z. Gudz'

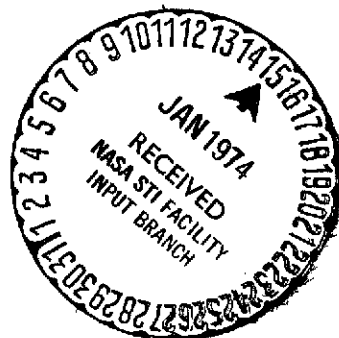
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16. Abstract Models of "trained" and "overtrained" organisms were created in experiments on animals (dogs, goats and rats). A histological study revealed progressive changes in the muscles of animals subjected to moderate and submaximal loads. These changes reflect an adaptation of the organism to physical loads. Destructive and dystrophic alterations of part of muscle fibers (breaks from tendons, ruptures and fragmentations, rosary-like swellings) were found in extremal muscles of the animals additionally subjected to the regime of prolonged maximum loads which produced a state of chronic fatigue ("overtraining"). "Trained" motor nerve endings became considerably dilated and contained a large number of terminals and nuclei of Schwann's glia. Chronically fatigued ("overtrained") motor nerve endings became distinctly reduced, as if compressed into a ball. Nuclei of Schwann's glia decrease in number, part of them is well impregnated.			
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MORPHOLOGICAL CHANGES IN MUSCLES AND NERVES OF
THE EXTREMITIES UNDER CONDITIONS OF "OVERTRAINING"

(AN EXPERIMENTAL-MORPHOLOGICAL INVESTIGATION)

P. Z. Gudz'¹

The application of large physical loads in sports training has today become very popular. There are data which indicate that high sporting indices are achieved only as the result of training in which predominantly maximal loads are employed. However, it is known that not all sportsmen who train with maximal load successfully rise to the heights of sporting achievements. Certain of them still at a young age, following a certain period of athletic growth, in repeated attempts cannot attain even their previous results and they gradually depart from the sporting arena.

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The studies of G. V. Fol'bort (1949) et al., M. Ya. Gorkin (1954) and others have shown that repeated physical loads can lead to the development of two contradictory conditions of the organism. If each subsequent load comes in a period of firmly restored condition, then the training process develops and there is an increase in the functional capacity of the trained organs and of the organism as a whole.

But if, in fact, the new load falls upon organs whose work capacity has not yet been restored, then a contrary condition develops — chronic fatigue — which in sports practice is conventionally termed overtraining.

This makes it necessary carefully to investigate the influence of large physical loads on the organism. An investigation of the morphological changes in the organism which have appeared under the influence of systematic training

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at high intensity will place in the hands of the specialist information through the use of which he will be able maximally to discover the potential properties of physical qualities of the sportsman, protecting him, however, from possible overtraining. In combination with the data concerning functional changes in the training organism, data on morphological changes in it will make possible solution of problems of expediently controlling the organism with the goal of its harmonious development and of subsequently increasing athletic achievements.

Problems of the clinics, physiology and biochemistry of training and overtraining of the organism have been the subject of a large number of studies (V. V. Gorinevskaya, 1931; G. V. Fol'bort, 1949; R. V. Chagovets, 1951; M. Ya. Gorkin, 1954; Sh. Yones, 1959; I. V. Muravov, 1955; V. V. Frol'kis, 1958; A. T. Dembo, 1959; O. V. Kachorovskaya, 1959; I. Kotaesku, 1959; A. Prokop, 1959; V. Smoldaka, 1959; N. N. Yakovlev, 1959, etc.).

It has been shown that in the process of training significant functional changes occur in the organism.

According to the data of F. E. Zvyagina, Ye. S. Mnukhina, N. N. Yakovlev, L. I. Yampol'skaya (1951) and others, in the trained muscle there is an increase in the oxidative and anaerobic resynthesis of adenosintriphosphoric acid, which is the basic source of energy for muscular activity. The authors have shown that muscular activity of various character leads to different biochemical changes. During long-term loads, carried out at moderate tempo, there is an increase in the content of glycogen, phosphagen, inorganic phosphorus and myoglobin in the muscle; there is a significant increase in phosphorolytic activity. An increase in the tempo of training leads to a significant increase in the glutathion, ascorbic acid, and in the activity of catalase and dehydrase. All these biochemical indices have varied qualitative expression, depending not only on the character of load, but also on the functional characteristics of the muscles. /56

But in addition to the large number of studies devoted to physiological and biochemical changes in trained muscles, only a few studies have been devoted to morphological changes in muscles under the influence of training

(Siebert and Petow, 1926; Hoffmann, 1947; Ye. S. Yakovleva, 1954; A. K. Koveschnikova, 1951, 1954, 1956). This is primarily explained by the fact that for the morphologist, the living trained human organism is less accessible than it is for the physiologist, clinician or biochemist. Anthropometry and x-ray mapping provide the possibility of studying primarily the skeletal and joint apparatus in the live subject. Sectioned material cannot yield adequate information on morphological changes in the organism under the influence of training, for in the extremely rare haphazard material, even with very careful investigation, one can obtain only a certain summary of information on final changes which have occurred in the organism; the dynamics of the very process of changes slip away from the investigator's attention.

Only the creation of an experimental model of "trained" and "overtrained" organism, using animals, can aid in solving this problem.

The works of Ye. S. Yakovleva (1954), A. K. Koveschnikova (1951), Hoffmann (1947), and Siebert and Petow (1926) provide a description of the morphological restructuring of muscles of experimental animals under the influence of comparatively small physical loads.

Our study is devoted to morphological changes in the muscles and nerves of the extremities, where, under the influence of large and predominantly maximal physical loads, which cause the condition of training and chronic fatigue, the so-called overtraining appear.

The study was made on goats, dogs and rats, which were "trained" on a treadmill and in a specially constructed apparatus.

This selection of animals for creating the experimental model is explained by the fact that in the process of evolution they acquired the capacity for long distance movement over land. Moreover, in rats, which have a comparatively short life cycle, it is possible in a brief period of time to trace the dynamics of processes occurring in man over the course of decades.

The experiments were conducted over the course of a year or more. In the last months of the experiment, against a background of good physical preparation, so-called training, one series of animals received maximum load to the

point of breakdown. Goats and dogs ran 4-6 hours per day at a speed of 7-15 km per hour. Rats ran at a speed of 1.5-2 km per hour, 5-6 hours per day.

Conditions of good physical training and chronic fatigue were established by various methods: electrocardiography, pneumography, volume of work accomplished, and by visual evaluation.

The controls were animals which had lived under conditions usual for them /57 or under conditions of limited movement (in small cells).

After killing the animals, various muscular groups of the anterior and posterior extremities were subjected to histological investigation. The sections were impregnated with silver nitrate after the method of Bil'shovskiy-Gros and were stained with hematoxylin-eosin and picrofucsin. It was found that under the influence of various physical loads, morphological changes of the muscular fibers appear in the muscles, as well as changes in the tendons and neuromuscular apparatus.



Figure 1. Separation of the Muscle Fiber from the Tendon (Arrow) in the Quadriceps Muscle of the Canine Hip, in a Condition of Chronic Exhaustion. Impregnation after Bil'shovskiy. Photomicrograph, objective 40, ocular 10.

In the animals which were kept under conditions of limited movement, acute dystrophy of parts of the muscular fibers appears. They lose their muscular condition, and apparently lose tonus, as a result of which the muscles lengthen. Therefore, against a background of unchanged muscle fibers, changes have sharply pronounced convolucional nature and more intense color. Longitudinal striation and particularly transverse striation in these muscles was very weakly pronounced.

Among the animals which received submaximal loads and which were in a condition of good physical



Figure 2. Separation of a Group of Muscle Fibers from Tendon (Arrow) in the Quadriceps Muscle of the Rat Hip; Rat in a Condition of Chronic Fatigue. Hematoxylin-eosin. Photomicrograph, objective 8, ocular 15.

preparation, the muscle fibers were straight and had clearly pronounced longitudinal and transverse striation. The motor patches were clear-cut, with broad bases and the large number of nuclei of Schwann glia.

Among the animals which received single maximal loads with a long-term rest period, against a background of good physical training, we did not find any pathological changes in the muscles.

Among the animals which were "trained" with the application of large, predominantly maximum physical loads over the course of a long period of time, as a result of which they were kept in a condition of chronic fatigue, pathological changes

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in certain muscles of the extremities were found (Figures 1 and 2).

In the quadriceps muscle of the hip of rats, goats and dogs, partial and total separations of the muscle fibers from the tendons were detected. In certain regions, an entire group of muscle fibers had torn away; in the muscle fibers which attached to the tendons at an angle, tears were observed in the region of the acute angle. These regions of the muscle fibers were usually strongly impregnated, which indicates their chemical restructuring.

Certain of the fibers which had broken away had grown from the end to neighboring fibers, and only a thin filament of sarcolemma connects them to the tendons. Along the path of the tendons, in places where they attach to the muscle fibers, one encounters coursed regions of the scar type. Here one notes increased argyrophilia of the collagen fibers.

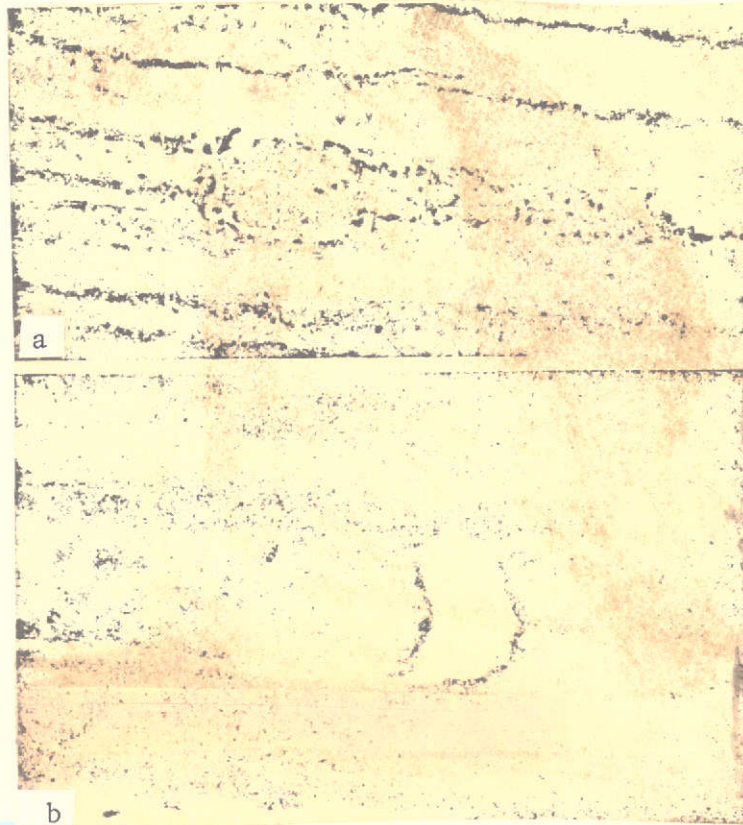


Figure 3. Fragmentation and Tearing of Muscle Fibers in the Biceps Muscle of the Hip of the Rat (a) and Dog (b) Which Were Kept in a Condition of Chronic Exhaustion. Hematoxylin-esion. Photomicrograph; a, 8×15 ; b, 40×10 .

In the biceps muscle of the hip, separations and fragmentation of the muscle fibers were found (Figure 3). At the end of the torn muscle fibers, one notes proliferation of cellular elements. In most cases, the fragments were compressed by intact muscle fibers which severely bend their termini.

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The short fragments are the remnants of muscle fibers which had been subjected to ceraceous degeneration. The long fragments are on the whole distinguished by increased argyrophilia. In the central area they retain their transverse striation, the termini are homogeneous, with signs of the initial stage of ceraceous degeneration. From the termini of certain fragments stretch a fine filament of sarcolemmal tubule. It is characteristic that the capillaries in such fragments are severely impregnated.

We also found similar changes in the semitendinous and semimembranous muscles of dogs and other animals which had been kept in a condition of chronic fatigue.

In rats, in the biceps muscle of the hip, in the semimembranous, semitendinous and gluteus maximus muscles, various sizes of muscle fibers sharply emerge. The exhausted muscle fibers are strongly convoluted. Some of the muscle fibers have ganglionic consistency with defibrillation of the myofibrils, clear-cut swelling and constrictions (reminiscent of bamboo poles). Such fibers are frequently unequally colored throughout their length. On the whole, they are distinguished by increased chromatophilia and argyrophilia.

Significant changes were also found in the gastrocnemius muscle. In the other muscles of the posterior extremities of animals which had been kept in a condition of chronic fatigue, there were no such severe changes. This is primarily explained by the fact that in four-legged animals the biceps, semimembranous, semitendinous, gluteus maximus and gastrocnemius muscles play a primary role in providing forward body movement of the animal and during a long run receive the largest load.

In the anterior extremities the muscle fibers of the biceps and triceps muscles of the shoulder underwent significant changes. Here, significant difference in circumference and different degrees of coloration of the muscle fibers are observed. The termini of the fibers near the tendons are sharply impregnated. Many of them along their length have clear-cut thickening and constrictions. The places of thickening of the muscle fibers have increased chromatophilia. Here, nuclei and transverse and longitudinal striation are entirely absent. In the narrow places, transverse striation is somewhat noticeable. Certain fibers contain a large amount of nuclei which are arranged in chains of three or four or more each. A large number of fibers have sharply pronounced fibrillarity. One encounters homogeneous fibers in which striation are absent and nuclei are only barely noticeable. This indicates deep destructive changes in these fibers (Figure 4).

The muscular nuclei of certain fibers have different degrees of coloration. Just as in the quadriceps muscle of the hip, in the triceps and biceps muscles of the shoulder one encounters total separations of muscle fibers from the

tendons and fascia. In areas of termination of tendons within the biceps' muscle, there is reactive irritation of the tendonous tissue.

The motor nerve fibers and their nerve endings in the muscles, under the influence of physical load, were also subject to significant changes (Figure 5). Under conditions of chronic exhaustion one notes mosaic changes in them.

A large portion of the preterminal ramuli has sharply pronounced varicose swelling, defibrillation and vacuolization of the axial cylinders. The myelin sheath of many of the nerve fibers is torn away and the Schwann nuclei are variously colored.

Weak coloration of the terminal ramuli of the motor termini is characteristic for most of the nerves of the muscles of the "overtrained" animals. The preterminals are sharply argyrophilic. This indicates deeper changes of the terminal regions of the motor nerves.

The motor patches of the muscles of the "overtrained" animals have a significantly diminished base, and they are as it were compressed into lumps. The number of nuclei with Schwann glia in them decreases to 4-5, and occasionally /60 even lower. Certain of the nuclei are strongly impregnated, which indicates irreversible changes in them, since the subsequent stage is their collapse. The motor spots on the fibers which were subjected to destructive changes frequently appear to be carbonized lumps, while at the same time, in a neighboring fiber, one notes hypertrophy of elements of the motor spot: an increase in the number of termini, nuclei, and expansion of the base.

A decrease in the dimensions of the motor nerve endings lowers the functional properties of the muscles and the decreased contact between the muscles in nerve fibers diminishes the secretion of chemically active substances in this region. It has come to be the case that the muscles contract more weakly. In most muscles of the animals' extremities, with respect to the animals which were kept in a condition of chronic "exhaustion", an increase in argyrophilic stroma of the muscles was detected as well as deposits of lipide drops in the muscles against a background of general emaciation, which is apparently the result of tissue hypoxia.

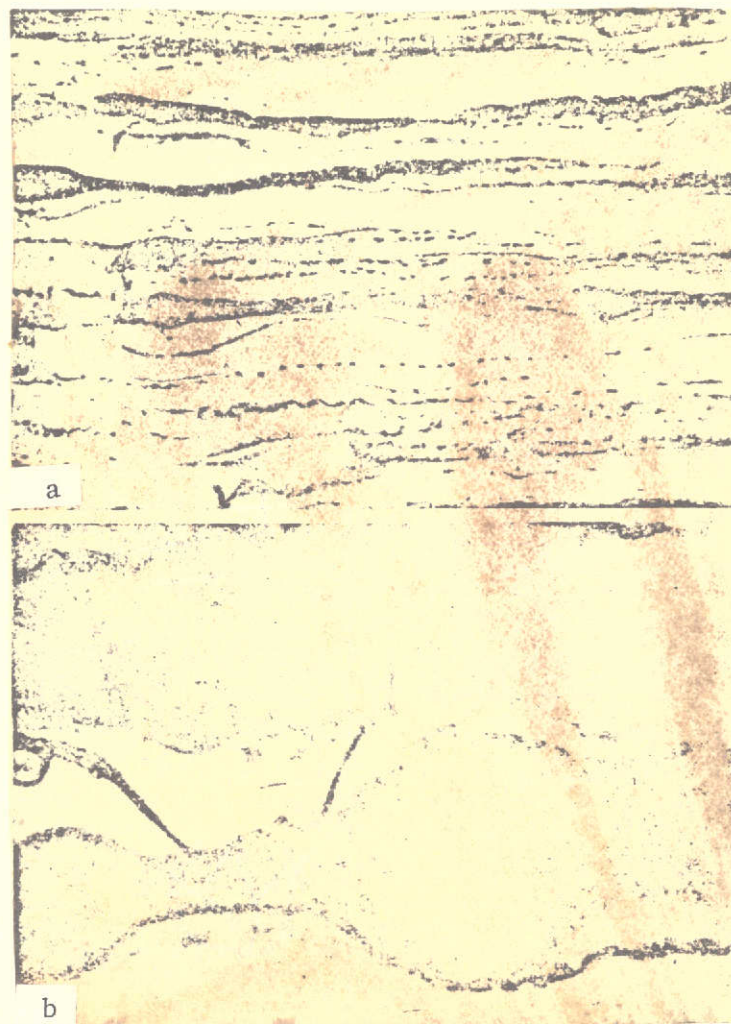


Figure 4. a, Dystrophy and destruction of part of the muscle fibers of the biceps muscle of the shoulder of the goat, kept in a condition of chronic exhaustion; b, Altered muscular fiber in high magnification. Impregnation after Bil'shovskiy. Photomicrograph; a, 8×7 ; b, 40×15 .

Hence, the cited data indicate that in the process of "training" animals /61
 with the application of large and predominantly maximum loads, in the muscles
 most active in the given study various destructive changes of the muscle fibers
 and neuromuscular elements appear; these vary in degree. Changes in the muscle
 fibers are most pronounced in the places of their attachment to tendons, i.e.,
 in locations of maximal application of force.

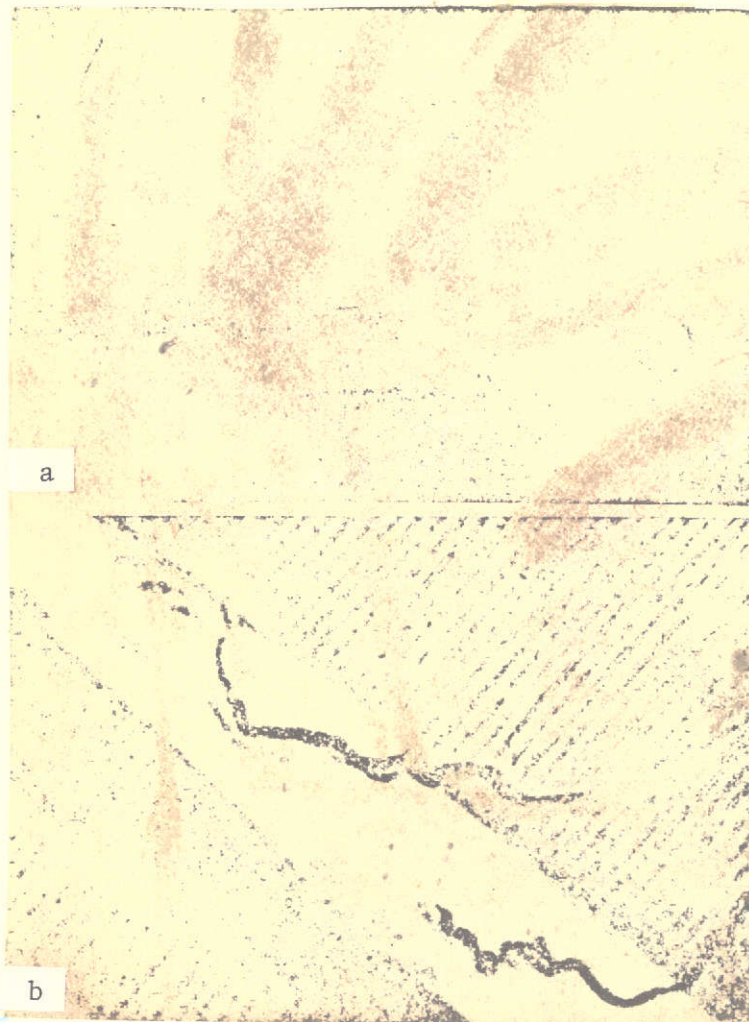


Figure 5. Motor Nerve Endings of the Semitendinosus Muscle of the Dog Hip. a, In a condition of good physical training, so-called "training"; b, In a condition of chronic exhaustion ("overtraining"). Impregnation after Bil'shovskiy. Photomicrograph, 40×15 .

An analysis of the described changes indicates that in a significant portion these changes are reactive, reflecting exhaustion of the neuromuscular apparatus and capable of reversing. Even fibers separated from the tendons do not always perish. Part of them grow up to the neighboring muscle fibers and apparently maintain their contractive properties.

However, certain fibers were subjected to irreversible changes which lead to complete deterioration and replacement by connective tissue.

The mosaic nature of changes in the muscles is explained by the fact that /62 under conditions of chronic fatigue, newer and newer muscle elements are drawn into the destructive processes at various times. At the moment the animal dies, these muscular elements are at various stages of reactive changes, destruction, and degeneration. On the other hand, as is known, during even the highest physical loads, under the influence of nerve impulses, not all muscle fibers contract. Part of the fibers are kept in reserve.

In the process of long-term work of the muscles, sequentially, various groups of muscle fibers are brought into action. In the period of fatigue, the coordinating role of the nervous system is disrupted, and in connection with this there is disruption in sequence of activation of the neuromuscular units.

Contractive impulses strike part of the muscle fibers in which the phase of total restoration has not yet begun. Repetition of such out of sequence impulses causes exhaustion of the contractive properties of the muscle fiber, which in the final analysis leads to their destruction which occasionally terminates in total deterioration.

It is important to note that all these changes occur in the muscle when the animal still has a high albeit somewhat diminished work capacity.

One can surmise that the same processes also occur in the organism of the sportsman who is training at maximal loads.

Gradual degeneration of part of the muscle fibers and their replacement with connective tissue in the final analysis leads to a diminution of their number in the muscles, and this entails a decrease in muscular strength.

An attempt of the sportsman to repeat and improve previous sporting results, being accompanied by maximal load, worsens the processes in the muscles. The muscle fibers which have remained unchanged are in no condition to compensate for the lost activity of altered muscles and the sporting results diminish.

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